

1 INSPECTION DEVICE FOR RADAR ABSORBING MATERIALS

3 BACKGROUND OF THE INVENTION

5 Field of the Invention

7 (001) The invention relates to the field of inspection devices and, in particular,
8 to a non-contacting inspection device to measure the thickness of radar
9 absorbing materials (RAM) applied to a conducting surface.

11 Description of Related Art

13 (002) A RAM coatings contains magnetic particles incorporated into a binder
14 such as a urethane paint. The thickness of the coating must be controlled in
15 order to obtain the proper radar absorption properties. One approach is to use
16 a hand held thickness measuring device as disclosed in US Patent No.
17 5,0112,248 "Radar Absorption Material Thickness Measuring Device" by J. R.
18 Munroe, et al. This invention comprises a radiating element assembly for
19 transmitting RF energy to and recovering reflected RF energy from the
20 coating. A visual display is provided to indicate the thickness of the coating.
21 A portable power supply is coupled to the detector assembly making it
22 portable. This device is highly suitable for use in checking repairs made in
23 the field. While this device works well, it requires contact with the surface.

25 (003) It is desirable to automate the application of RAM coating by use of
26 robotic spray machines. However, since coating thickness is critical, it is
27 desirable to check the coating thickness prior to it curing. This would make
28 the by J. R. Munroe, et al. device unusable because of the damage to the
29 coating that would occur upon movement of the device across the wet surface.
30 This problem can be avoided by the use of radiating and receiving horns

1 angled toward each other. The signal from the radiating horn is directed at the
2 surface and the return signal is picked up by the receiving horn. However, the
3 horns must be positioned at 12 inches from the surface. Thus the
4 measurement is limited to relatively large areas. This prevents accurate
5 readings of significantly curved surfaces. Furthermore, it can not be used in
6 confined areas such as the engine inlet ducts on aircraft.

7
8 (004) Conventional inspection techniques such as those, which use ultrasonic
9 techniques, are unsuitable, for radar absorption is not measured, because
10 ultrasound does not propagate well in loaded urethane or silicon based
11 materials. Thus it is possible that the thickness may be correct, but the area
12 may not properly loaded with magnetic materials.

13
14 (005) Thus, it is a primary object of the invention to provide a thickness and
15 radar performance inspection device for inspecting RAM coatings.

16
17 (006) It is another primary object of the invention to provide a non-contacting
18 thickness inspection device for inspecting RAM coatings

19
20 (007) It is a further object of the invention to provide a thickness inspection
21 device for inspecting RAM coatings that have been applied to curved surfaces.

22
23 (008) It is a still further object of the invention to provide a thickness
24 inspection device for inspecting RAM coatings that inspected surfaces located
25 in confined areas.

26 27 **SUMMARY OF THE INVENTION**

28
29 (009) The invention is device for inspecting an assembly that including a
30 surface coating containing radar-absorbing materials on a conductive surface

1 or substrate. In detail, the device includes a first circuit for transmitting an
2 electromagnetic signal to the assembly. The first circuit includes a radio
3 frequency (RF) source of electromagnetic radiation coupled to a waveguide
4 made of a conductive material coupled in series to a second wave guide made
5 of a dielectric material with their longitudinal axis aligned. A second circuit is
6 provided for receiving the portion of the electromagnetic radiation transmitted
7 by the first circuit reflected from the assembly. The second circuit includes a
8 third waveguide made of a conductive material coupled in series to a fourth
9 waveguide made of a dielectric material with their longitudinal axis aligned.
10 The second circuit further includes a RF power detector coupled to the third
11 waveguide. Thus an electromagnetic signal is transmitted from the first
12 waveguide to the second waveguide on to the assembly and the portion of the
13 electromagnetic signal reflected off the assembly is received by said fourth
14 waveguide and transmitted to said third waveguide and to the RF power
15 detector. The longitudinal axes of the first and second waveguides are at an
16 acute angle to the longitudinal axis of the third and fourth waveguides. This
17 angle is preferably 10 degrees.

18
19 (010) The second and fourth waveguides are solid and made of a dielectric
20 material such as a Polytetrafluoroethylene. It is important to provide an
21 impedance match between the first and second waveguides and the third and
22 fourth waveguides, and the first and fourth waveguides to free space. This is
23 accomplished by having the center portion of the second and fourth
24 waveguides fit within the first and third waveguides. A portion of the second
25 and third waveguides extend into the first and third waveguides are tapered
26 along their top and bottom surfaces to a relatively sharp edge at the end there
27 of. A portion of the waveguides on the ends extending out of the first and third
28 wave guides are tapered along their sides to a relatively sharp edge.

1 (011) The output from the RF power detector is fed to a programmable gain
2 amplifier and thereafter to a signal digitizer. The programmable RF source
3 and RF power detector, as well as the amplifier and signal digitizer are
4 typically controlled by a microprocessor. The second and fourth waveguides
5 maintain about 0.75 inch away from the surface of the assembly being
6 inspected. Thus the device is typically mounted on a robotic arm, such that
7 the assembly is automatically inspected, in a manner similar to the robotic
8 spray machines used to apply the coating. Thus the inspection process is no
9 different from other automated inspection systems. However, this device
10 allows the coating to be inspected prior to its curing, while still in a wet
11 condition. Thus any issue associated with the material and the application
12 process can be corrected prior to the coating curing.

13
14 (012) The novel features which are believed to be characteristic of the
15 invention, both as to its organization and method of operation, together with
16 further objects and advantages thereof, will be better understood from the
17 following description in connection with the accompanying drawings in which
18 the presently preferred embodiment of the invention is illustrated by way of
19 example. It is to be expressly understood, however, that the drawings are for
20 purposes of illustration and description only and are not intended as a
21 definition of the limits of the invention.

22 23 **BRIEF DESCRIPTION OF THE DRAWINGS**

24
25 (013) Figure 1 is a block diagram of the subject device

26
27 (014) Figure 2 is a side view of a robotic arm incorporating the subject device

28
29 (015) Figure 3 is a top cross-sectional view of the first and second
30 waveguide.

1
2 (016) Figure 4 is a side cross-sectional view of the first and second
3 waveguides shown in Figure 3.

4
5 (017) Figure 5 is a chart providing the dimensions of the third waveguide for X
6 and C band electromagnetic transmissions.

7
8 (018) Figure 6 is a graph of typical reflection loss verses frequency for varies
9 cure times for a typical RAM coating.

10
11 (019) Figure 7 is graph of reflection loss as a function of frequency for various
12 RAM coating thickness for the material plotted in Figure 6.

13
14 (020) Figure 8 is a graph of the detection sensitivity verses detection
15 sensitivity for a 0.030-inch coating thickness for the typical RAM coating.

16
17 (021) Figure 9 is a graph of the standoff distance of the device verses
18 reflection loss.

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20 (022) Figure 10 is a graph of the device incident angle verses reflection loss.

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22 (023) Figure 11 is a graph of the beam pattern.

23
24 (024) Figure 12 is a graph of the predicted reflection loss of a plate with 50
25 percent of the surface covered with the RAM coating

26
27 (025) Figure 13 is a graph of the predicted reflection loss of metal plate fully
28 covered with the typical RAM coating having a portion with a reduced
29 thickness

1 (026) Figure 14 is a graph of the predicted reflection loss of metal plate fully
2 covered with the typical RAM coating having a portion with an increased
3 thickness.
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5 **DESCRIPTION OF THE PREFERRED EMBODIMENT**

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7 (027) Referring to Figure 1, the structural assembly, indicated by numeral 10,
8 comprises a conductive metal substrate 12 having a coating 14 loaded with
9 magnetic particles (not shown). This coating 14 will absorb a portion of
10 electromagnetic energy (radar beams) and reflect the remainder. The subject
11 inspection device, generally indicated by numeral 16, includes a RF source of
12 electromagnetic energy 18, which feeds a first conductive (metal) waveguide
13 20, which is connected in series with a solid waveguide 22 made of a dielectric
14 material. A suitable RF generator 18 is a fixed frequency type produced by
15 Lucix Technology, Camarillo, California. Variable or programmable RF
16 generators can also be used. The first and second waveguides 20 and 22
17 have an aligned longitudinal axis 24. Preferably, the second waveguide is
18 made of Polytetrafluoroethylene (PTFE), for example TEFLON® manufactured
19 by the E. I. duPont de Nemours & Company, Delaware.
20

21 (028) The waveguide assembly 16 further includes a third waveguide 26,
22 made of conductor (metal), which is connected in series with a fourth solid
23 wave guide 28, also made of a dielectric material. The third and fourth
24 waveguides 26 and 28 also have a common longitudinal axis 30. The
25 longitudinal axis 24 of the first and second waveguides 20 and 22 is at an
26 acute angle 32 to the longitudinal axis 30 of waveguides 26 and 28. This
27 acute angle 32 is preferably 10 degrees.
28

29 (029) Thus when electromagnetic radiation from the RF source 18 is provided
30 to the waveguide 20 and is directed to the waveguide 22 where it exits at end

1 34 and strikes the assembly 10 the portion reflected back enters the
2 waveguide 28 and travels to waveguide 26. The waveguide 26 is electrically
3 connected to a RF power detector 35. A suitable power detector is obtainable
4 from Krytar Corporation, Sunnyvale, California. For best results, the
5 waveguides 22 and 28 should be at a distance 36 of 0.75 inch (which will be
6 subsequently discussed). The detail design of these waveguides 20, 22 and
7 26 and 28 will be subsequently discussed.

8
9 (030) The output from the RF power detector 35 is coupled to programmable
10 gain amplifier 37, which, in turn, is coupled to an analog signal digitizer 38.
11 The amplifier 37 and digitizer 38, as well as the RF source 18 are all
12 connected to the microprocessor 40. A suitable micro-controller module with a
13 built-in digitizer is obtainable from Micromint, Incorporated, Lake Mary, Florida.

14 A LCD display 44 and keypad 46 are also coupled to the microprocessor 40.
15 The microprocessor 40, in turn, is typically coupled to a radio modem 48
16 and/or other external interface 50. Thus, as illustrated in Figure 2, the
17 microprocessor 40 could interface with the robotic machine 60 with the device
18 16 attached to a robotic arm 61 for automated inspection. However, for
19 purpose of defining the invention in its broadest sense, the first, second, third
20 and fourth waveguides 22, 24, 26 and 28, and RF generator 18 and RF
21 detector 35 are the main elements.

22
23 (031) In Figures 3 and 4, top and side views of the waveguides 20 and 22 are
24 presented and in Figure 5 a table of the values of the dimensions are
25 presented for both X and C band wave guides. The waveguide 20 is
26 conventional and its length and critical dimensions can be easily calculated..
27 Waveguide 20 has an open first end 62 and a closed off second end 64,
28 incorporating terminal 65 coupled to RF source 18. The waveguide 20 has an
29 internal height 66 and an internal width 68 dictated by the frequency of the
30 electromagnetic energy behind provided thereto. However, waveguide 22 (and

28) are shaped to provide impedance matching. Waveguide 22 includes a central portion 72 having a length 73, and an external height and width equal to the internal height 66 and internal width 68, respectively, of the waveguide 20.

The waveguide 22 further has an end portion 74 further extending into the waveguide 20 having a length 75 and top and bottom surfaces 76A and 76B tapering to an edge 78. The waveguide 22 further includes a second end portion 80 having a length 81 and left and right sides 82A and 82B tapering to an edge 84. Again the dimensions of the waveguide for both K and C band are provided in Figure 5. The dielectric waveguide serve two purposes: 1) funnel the electromagnetic radiation signals to close proximity to the structure 10 to be tested; and 2) create a matching impedance transition for the metal waveguides 20 and 26 to free space to maximize the signal transmission and reception efficiency.

(032) Tests were conducted to determine the proper test frequency. This was important because one of the main applications is to test the coating prior to curing. A typical reflection loss verses frequency for various cure times for a typical RAM coating is provided in Figure 6. Note that the reflection loss below 9GHz is about equal regardless of the cure time. Thus using a frequency below 9GHz would yield a reflection loss that would be independent of the degree of cure. However, when one looks at the reflection loss as a function of frequency for various coating thickness as illustrated in Figure 7, the issue becomes more complex. The dB reflection loss initially increases with frequency, but then starts to decrease as frequency increase. This indicates that if a single inspection frequency were used the inspection range of the coating thickness should be limited accordingly to avoid ambiguity.

(033) Plotting coating thickness verses reflection for varies frequencies, as illustrated in Figure 8, provides a better insight into the problem. Note that the four 4 and six 6GHz graphs show that the reflection loss magnitude increases

1 with coating thickness monotonically. At 10 GHz, the reflection loss magnitude
2 increases with coating thickness up to about 0.050-inch. Further increase in
3 coating thickness results in a decrease of reflection loss magnitude. Thus for
4 a 10 GHz single test frequency system, a thickness range of 0 to 0.45-inch
5 may be achieved by simple data processing schemes. In order to measure
6 RAM coating thickness using reflection loss at a single frequency without
7 ambiguity, the test frequency must be lower than the center frequency at the
8 high end of the thickness range.

9
10 (034) Given a desired thickness measurement range, the data in Figure 7
11 gives some insight to the resulting system's sensitivity. For example, a
12 thickness measurement range of 0 to 0.045-inch is required. All four
13 frequencies in the graph have a monotonic reflection loss with the coating
14 thickness. Using a 4GHz test frequency, the measurement system would
15 have a full scale reflection loss of 1.8 dB for the thickness range. While a
16 10GHz system would have a reflection loss of 10dB for the same thickness
17 range. Computing the slope for each trace in Figure 7 yields the detection
18 sensitivity of each test frequency. The table in Figure 8 summarizes the
19 detection sensitivity for a coating of 0.30-inch.

20
21 (035) The detection sensitivity is given in dB/(0.001-inch). This value signifies
22 the amount of signal change in dB for each 0.001-inch change in the coating
23 thickness. For example, increasing the coating thickness from 0.030-inch to
24 0.031-inch, the 4 and 10GHz reflection loss would increase by 0.44dB and
25 0.278dB, respectively. If the device has a reading resolution of 0.1dB, it would
26 not be able to detect be able the thickness at 4GHz. Small detection
27 sensitivity values indicate the system would be insensitive to a small thickness
28 change or would have less thickness detection resolution. The above
29 suggests that 10GHz would yield the best measurement sensitivity among the
30 four tests frequencies for the selected RAM coating. However the graph in

Figure 6 shows that the 10GHz reflection loss is sensitive to cure status. Thus if the frequency were reduced to 8GHz, it would reduce this sensitivity to cure condition without a significant loss in detection sensitivity.

(036) Tests were conducted to determine standoff sensitivity. An Aluminum plate was irradiated at 90 degrees incident angle at 0.125-inch increments. Figure 9 is a graph of the standoff-distance verses reflection loss. The graph shows three distinct steps prior to a large drop off at 1.5 inches. The 0.125 to 0.5 inch range was considered to provide too small of a buffer from the test surface. Thus the second step between 0.6 to 0.9 inch was selected with the previously mentioned 0.75 inch being the middle point.

(037) Figure 10 represents a plot of device incident angle verses reflection loss using the Aluminum plate as a target. When the plate surface was rotated towards alignment (counter clockwise) with the transmitting waveguide the reflection loss was mild. However, when rotated in the clockwise direction, drop off was more pronounced. But despite this biased response, it can be seen that the device can tolerate a four-degree incident angle change and still keep the reading discrepancy within 0.1dB.

(038) Tests were run to determine the beam pattern. Referring the Figure 11, a 0.125-inch diameter, 12 inch long brass rod was moved plus and minus 1.5 inches in 0.125 step increments in a direction perpendicular to the device (X direction) and passed by the device at a distance of 0.625-inch. The plot of transverse distance verses reflection loss indicates that a practically flat response is obtained within a transverse distance of approximately 0.4-inch. The minus three dB beamwidth of the device is approximately 1.5 inch.

(039) The sensitivity to nearby features was also examined numerically by convolving the beamwidth of the device and the reflectivity of different coated

1 surfaces. As shown in Figure 12 a conductive plate was coated over one half
2 of its surface with a RAM coating designed to provide a 3.7dB attenuation at
3 10GHz. As the device moves to the right, the expected 0dB reading from the
4 bare surface is reached at approximately 1.4 inches from the edge. As the
5 device approaches the coating the dB reading starts to approach the expected
6 3.7dB attenuation. As the coated edge is approached, the attenuation rapidly
7 increases.

8
9 ((040) Figure 13 illustrates the effect of a localized decrease in coating
10 thickness of a RAM coating. The coating provides an attenuation of 3.78 dB on
11 an aluminum substrate. The thin area of the coating was 0.030-inch thick and
12 0.125-inch wide and 0.005 inch deep. The attenuation only decreased by 0.06
13 dB to 3.72dB and the original reflection loss was restored at about 1.4 inches
14 from the recess. Figure 14, on the other hand illustrates the effect of a slight
15 increase in coating thickness (a 0.125-inch wide 0.005-inch increase in
16 thickness). The effect was a 0.1dB increase in attenuation to 3.88dB. At
17 about 1.4 inches away from the increase, the original reflection loss was
18 restored.

19
20 (041) Thus it can be seen that the device can provide non-contacting
21 measurement of RAM coatings of various thickness and degree of cure. It can
22 accommodate surface irregularities and is readily adaptable to robotic
23 inspection systems. It can also be adapted to various types of RAM coating
24 types.

25
26 (042) While the invention has been described with reference to a particular
27 embodiment, it should be understood that the embodiment is merely
28 illustrative, as there are numerous variations and modifications, which may be
29 made by those skilled in the art. Thus, the invention is to be construed as
30 being limited only by the spirit and scope of the appended claims.

1 **INDUSTRIAL APPLICABILITY**

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3 (043) The invention has applicability to inspection equipment industry.